Transactions of the Korean Nuclear Society Autumn Meeting
Changwon, Korea, October 30-31, 2025

Surface Characteristics and Corrosion Behavior of Alloy 600 Subjected to Underwater Laser Peening Treatment

Baosheng Bai[a*], Wongeun Yi[b], Eunsub Yun[c], Chi Bum Bahn [a]
[a]*Pusan National University, 63 beon-gil 2, Busandaehag-ro, Geumjeong-gu,Busan 46241*
[b]*Doosan Enerbility, 22 Doosan-volvoro, Changwon Gyeongnam, 642-792*
[c]*Korea Hydro & Nuclear Power, 70, Yuseong-daero 1312beon-gil, Yuseong-gu, Daejeon, 34101*
E-mail: bahn@pusan.ac.kr

****Keywords* :** Underwater laser peening, Electrochemical Corrosion, Residual stress, Microstructure, Alloy 600

1. Introduction

Alloy 600 is widely used in the nozzles of reactor pressure vessels and the tubes of steam generators in nuclear power plants. However, this material is susceptible to stress corrosion cracking (SCC) when exposed to a primary coolant environment involving high temperatures and pressures. The first case of primary water stress corrosion cracking (PWSCC) in Alloy 600 was reported in France in 1991 [1]. Therefore, enhancing the SCC resistance of the material is crucial for extending the service life and reliability of nuclear components, thereby ensuring the safe operation of nuclear power plants [2]. Surface stress modification is considered one of the effective approaches to mitigate PWSCC. Underwater laser peening (ULP) is an advanced surface treatment technique, in which laser irradiation induces the formation of high-temperature and high-pressure plasma on the material surface. The rapid expansion of plasma generates compressive loading, leading to plastic deformation and the introduction of compressive residual stresses (CRS) [3]. Compared with conventional shot peening techniques, ULP can generate a much deeper CRS field (greater than 1 mm), while providing excellent controllability and eliminating the risk of introducing foreign substances into the reactor. After ULP treatment, surface roughness, grain structure, and residual stress distribution undergo significant modifications, which in turn affect the corrosion behavior. Hence, it is necessary to systematically investigate the influence of ULP-induced surface changes on the corrosion behavior of Alloy 600.

In this study, Alloy 600 specimens were treated with ULP, and the resulting changes in surface morphology, roughness, hardness, residual stress, and microstructure were systematically analyzed. Subsequently, the specimens were exposed to a 3.5 wt.% NaCl solution for electrochemical testing. The electrochemical behavior of the alloy in the chloride-containing environment was evaluated by electrochemical impedance spectroscopy (EIS) and potentiodynamic polarization test.

2. Experimental Method

The chemical composition of the Alloy 600 used in this study was analyzed, and the results showed that it contained 73.8% Ni, 16.1% Cr, 9% Fe, 0.2% Mn, 0.01% Nb, 0.29% Si, 0.19% Ti, and 0.07% C. Plate specimens, as shown in Figure 1, were subjected to single and double ULP treatments over a central area of 25 mm × 25 mm. To simulate the surface condition of actual components, the specimen surfaces were pretreated by heavy grinding (HG) prior to ULP. Surface morphology was observed using optical microscopy. The residual stress depth profiles were measured using the hole-drilling method. The microstructural characteristics were analyzed by EBSD.

Electrochemical tests were conducted in a 3.5 wt.% NaCl solution using a conventional three-electrode cell. After the open circuit potential (OCP) stabilized, electrochemical impedance spectroscopy (EIS) and potentiodynamic polarization measurements were performed.

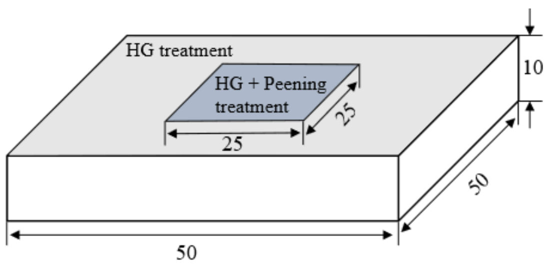

Fig. 1. Schematic of treatment specimen surface. x direction: grinding and peening process direction, y direction: treatments step direction.

3. Results

3.1 Surface Roughness and Residual Stress

The surface roughness of the specimens before and after ULP treatment is shown in Figure 2. The surface roughness increased after ULP treatment and further increased with the number of treatments. Figure 3 presents the depth profiles of compressive residual stress before and after ULP. It is evident that ULP treatment induced a CRS field extending to a depth of at least 1 mm. Within the near-surface region (up to 0.2

mm), the specimen subjected to a single ULP treatment exhibited higher compressive residual stress.

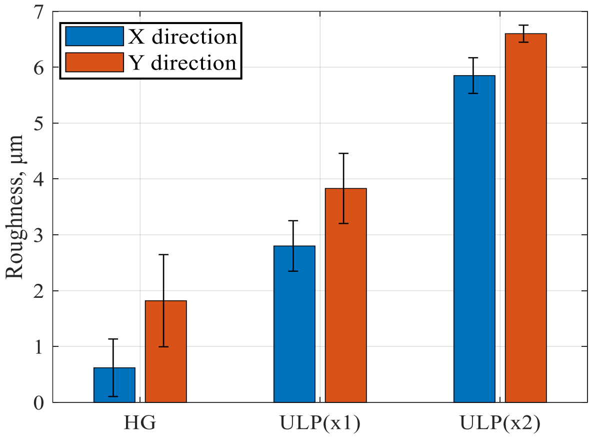

Fig. 2. Surface roughness measurement results after ULP treatment.

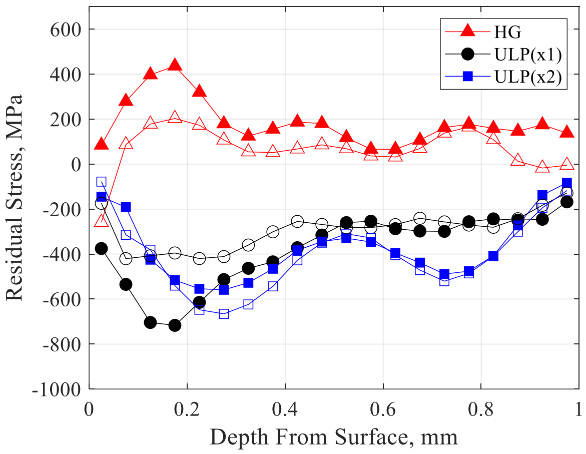

Fig. 3. Measurement results of compressive residual stress at a depth of 1 mm near the surface after ULP treatment.

3.2 Microstructure

The grain structures of different treated surfaces are shown in Figure 4. Plastic deformation induced by HG resulted in grain refinement from the nanometer to the micrometer scale. However, no significant grain refinement was observed on the ULP-treated surfaces. This is attributed to surface removal caused by laser ablation and the action of high-temperature, high-pressure plasma, a phenomenon that has also been reported in previous studies. After two successive ULP treatments, plastic strain accumulation at the surface led to the refinement of larger grains to the micrometer scale.

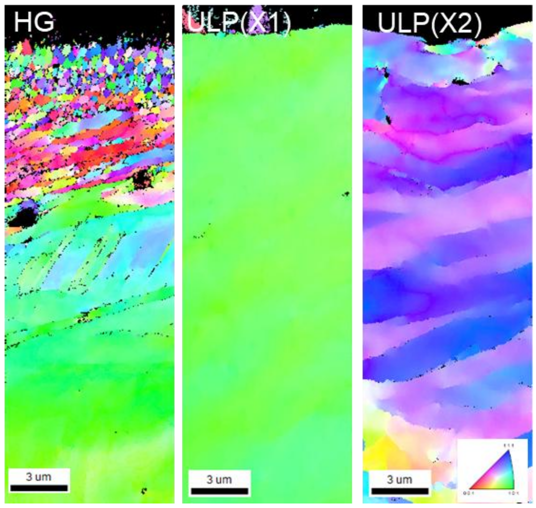

Fig. 4. Cross-section EBSD analysis results after ULP treatment.

3.3 Electrochemical test

Figure 5 shows the polarization curve of the HG surface. The corrosion potential is approximately −200 mV, with a corresponding corrosion current density of about 10^{-8} A/cm². A passive region is observed up to ~+200 mV, beyond which the passive current density gradually increases, indicating a decrease in film stability at higher anodic potentials. The polarization behavior of the ULP-treated surface is currently under investigation.

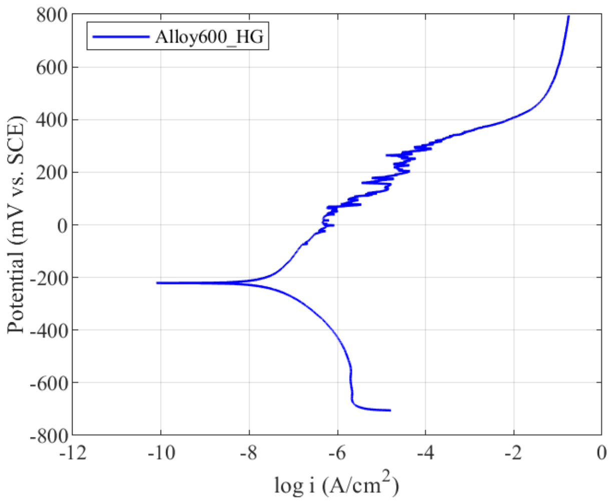

Fig. 5. Potentiodynamic polarization results of Alloy 600 after HG treatment.

4. Conclusions and Future Work

In this study, single and double ULP treatments were applied to Alloy 600, and the effects on surface roughness, residual stress, and microstructure were analyzed. The main conclusions are summarized as follows:

ULP treatment introduced a CRS field extending to at least 1 mm in depth on the surface of Alloy 600, which is beneficial for mitigating SCC.

Increasing the number of treatments had no significant effect on the depth of compressive residual stress, but it led to higher surface roughness and induced grain refinement after double treatment.

Future work will focus on conducting EIS and potentiodynamic polarization tests to further clarify the effect of surface modifications on the corrosion behavior of Alloy 600.

Acknowledgment

This study was financially supported by Korea Hydro & Nuclear Power Co., Ltd. (No. L20S019000). It was also supported by the 'Human Resources Program in Energy Technology' of the Korea Institute of Energy Technology Evaluation and Planning (KETEP), which was funded by the Ministry of Trade, Industry & Energy (MOTIE. Korea). (No. RS-2024-00398425).

REFERENCES

[1] Hwang S S. Review of PWSCC and mitigation management strategies of Alloy 600 materials of PWRs[J]. Journal of nuclear materials, 443(1-3): 321-330, 2013.

[2] Kai, J.J., Tsai, C.H., Huang, T.A. et al. The effects of heat treatment on the sensitization and SCC behavior of INCONEL 600 alloy. Metall Trans A 20, 1077–1088 (1989). https://doi.org/10.1007/BF02650143.

[3] M.A. Attolico, C. Barile, C. Casavola, V. Moramarco, D. Furfari, D.O. Busse, Effects of Laser Shock Peening on Surface Roughness and Residual Stress of AA 7050-T7451, J. of Materi Eng and Perform 31 (2022) 7973–7988. https://doi.org/10.1007/s11665-022-06857-7.